

Each day the resilience of the Earth offers humanity a new beginning by mitigating the pollution and wastes of yesterday. Through wind and water, pollutants are dispersed and diluted; through physical and chemical degradation, toxins are eliminated; and through the fidelity of DNA replication, life begins anew. But for a small group of persistent organic pollutants (POPs), natural processes and ecosystem services have proven inadequate to rectify, and in some cases have contributed to, environmental contamination. The resistance of POPs to degradation and their environmental persistence serve as a foundation for prolonged and disseminated adverse effects. Air and water move POPs far from their site of release to the environment, including to previously pristine locations such as the Arctic. The low levels of POPs reaching remote locations can then be reconstituted to potentially toxic levels through bioaccumulation in the food chain. And, most poignantly, the first exposure of offspring may be through a loading dose of toxin to the fetus or in milk, during the most sensitive period of develop-

ment. It is to this group of substances—the persistent organic pollutants—that this technical report is addressed.

The report summarizes the science underpinning contemporary action on POPs, focusing on the 12 substances or substance groups prioritized for global action in the recently signed Stockholm Convention on Persistent Organic Pollutants, developed under the auspices of the United Nations Environment Programme (UNEP). These 12 substances, the "dirty dozen," are:

- \* Pesticides: dieldrin, aldrin, endrin, chlordane, heptachlor, DDT, toxaphene, mirex
- \* Industrial chemicals: polychlorinated biphenyls (PCBs; also a byproduct), hexachlorobenzene (HCB; also a pesticide and byproduct)
- \* Byproducts: polychlorinated dibenzofurans, polychlorinated dibenzo-*p*-dioxins (dioxin)

The report is directed toward educating decision-makers, academia, and the public on the foundation and relevance to the United States of the Stockholm Convention on POPs. The report consolidates and summarizes the large volumes of data developed on these substances over decades of scientific concern and regulatory experience, as published in multiple source documents from individual peer-reviewed literature, through single-chemical profiles, to multivolume risk assessments. Its objective is to provide an overview of the human and ecological risks posed by POPs to U.S. ecosystems and citizenry. Emphasis is placed on making the document easily readable, while maintaining its technical accuracy and balance. To this end, citations are provided to more comprehensive and detailed literature for those seeking a more complete elaboration of technical issues.



*PCB concentrations are elevated in Aleutian Island sea otter populations.*

Photo: U.S. Fish and Wildlife Service

### Why Focus on POPs?

Public concern and scientific and regulatory efforts regarding this small group of pollutants encapsulate the genesis and development of environmental pollution awareness in the United States. These are the pollutants that Rachel Carson wrote about in *Silent Spring* (Carson, 1962), which contaminated Agent Orange during the Vietnam War, and contributed to Love Canal, NY, Times Beach, MO, and numerous other pollution episodes. All 12 substances prioritized under the Stockholm Convention are now deregistered, banned, or out of production in the United States, or their emissions have undergone major reductions. Yet their effects are still felt through a legacy of past pollution, continuing emissions, and movement across international borders.

For the nine organochlorine pesticides (including hexachlorobenzene as a fungicide), the extent of adverse human health and/or ecological effects led to the withdrawal of all registered uses in the



Poor storage of donated DDT in Zanzibar.

Photo: R. Hedlund, USAID



Dieldrin-containing drums in Niger.

Photo: Janice Jensen

United States during the 1970s–1990s, either by the U.S. Environmental Protection Agency (EPA) or voluntarily by the registrant. Production of the last of these, heptachlor, has ceased and its registration was voluntarily cancelled in 2000. Because U.S. pesticide laws are based on registrations for specific uses, problem chemicals are dealt with through withdrawal of these registrations, rather than bans on production. The net effect of these actions is that there is currently no production of any of the POPs in the United States for sale domestically or internationally, except for laboratory-scale research consistent with the requirements of the Stockholm Convention.

For polychlorinated biphenyls (PCBs), the magnitude of environmental problems was central to the passage of the Toxic Substances Control Act (TSCA). PCB production was banned under this legislation in 1979, although production ceased prior to this date. Existing PCBs in electrical equipment must be prevented from entering the environment and destroyed at the end of the equipment's service life. Polychlorinated dibenzo-*p*-dioxins and polychlorinated dibenzofurans, better known as "dioxins," have been controlled through a variety of means, principally emission controls on incinerator sources, process changes to remove elemental chlorine from pulp and paper production, and the deregistration of contaminated herbicides such as 2,4,5-trichlorophenoxyacetic acid (2,4,5-T; a constituent of Agent Orange).



The breadth of POPs pollution that led to these U.S. regulatory actions is still evident in contemporary environmental concentrations. POPs pollution has touched every region of the United States, as illustrated by the geographic distribution of current DDE (a long-lived toxic metabolite of DDT) and PCB concentration elevations in coastal mussels (Figure 1-1) and PCB fish advisories (Figure 1-2). Impacts on the Great Lakes (Chapters 3, 4) and marine ecosystems (Chapter 6) are highlighted in

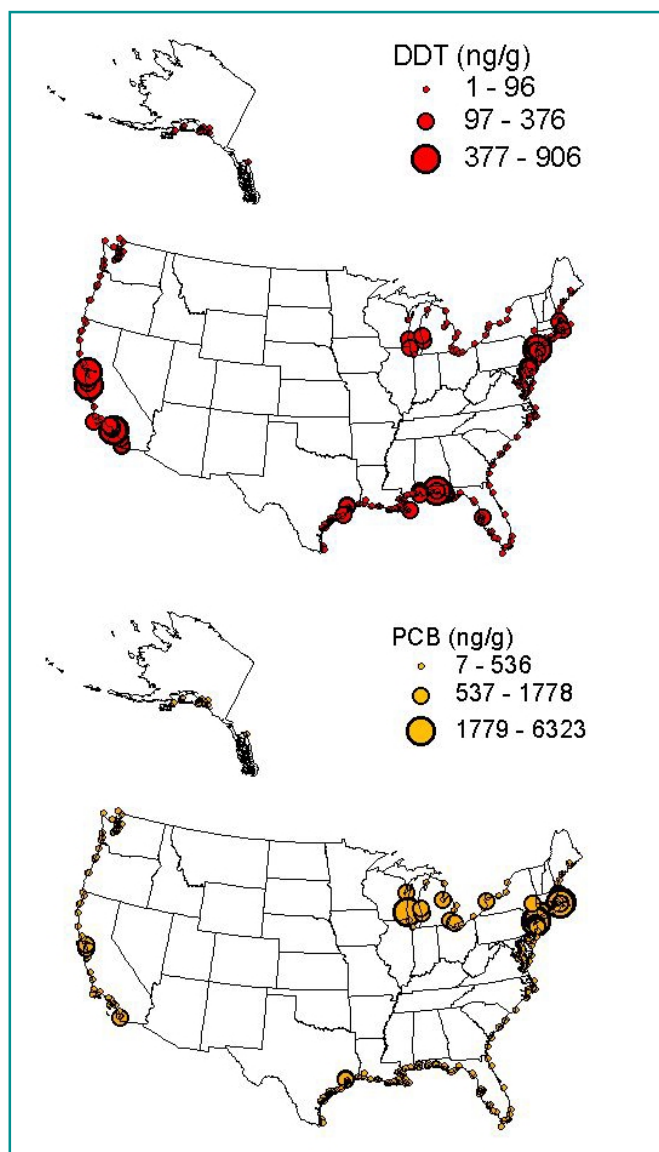


Figure 1-1. Sum-DDT and sum-PCB concentrations in coastal mussels (dry weight) collected by the National Oceanic and Atmospheric Administration (NOAA) through its ongoing Status and Trends Mussel Watch Program. <http://ccma.nos.noaa.gov>. See also trends discussion in Chapter 6.

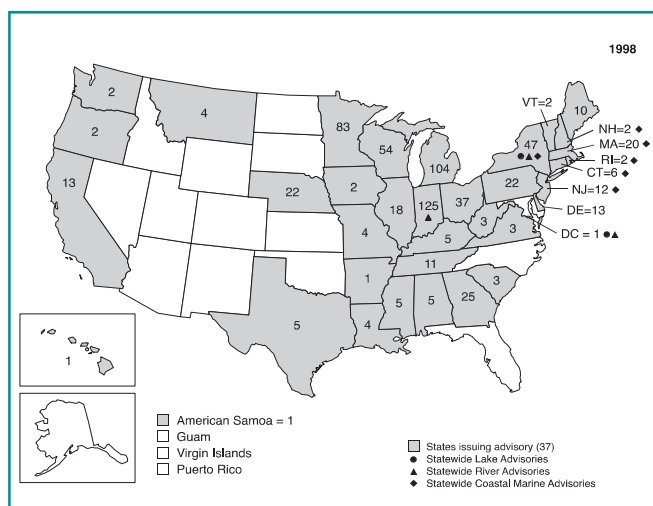


Figure 1-2. 1998 fish consumption advisories reported for polychlorinated biphenyls (PCBs) to the U.S. EPA by States, Territories, and Native American tribes. See Chapter 4 for further details on fish advisories. U.S. EPA 1999.

this report as examples of POPs pollution exposures and effects, along with a summary of the existing science on POPs concentrations and risks in Alaska (Chapter 5). Many more sites of POPs contamination are scattered across the United States, but these cannot be detailed here because of space constraints. One such example is Lake Apopka in Florida, where high levels of several POPs (principally DDE) and other pollutants in the alligators (Figure 1-3) have been postulated as causing reproductive impairment and male genital abnormalities in alligators following embryonic exposure, although the specific causal agent(s) remains uncertain (Guillette et al., 1999).

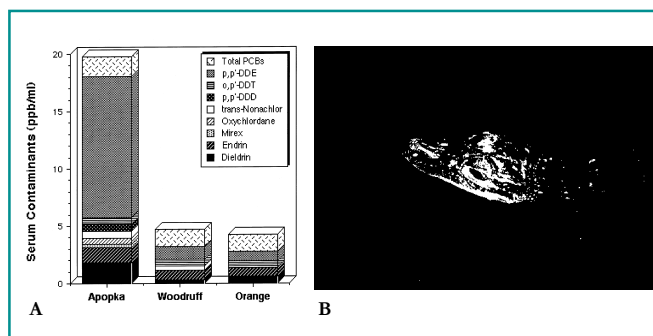


Figure 1-3. A. POPs contaminant serum levels in juvenile alligators from three different lakes with the same drain-age in Florida. B. A yearling alligator swimming in the eutrophic water of Lake Apopka.

Photo: Howard K. Suzuki

The extent to which POPs remain problematic is also manifest through continuing regulatory and policy initiatives, both domestically and in international fora in North America. Domestically, the EPA is engaged in a variety of persistent bioaccumulative toxin (PBT) initiatives. PBTs encompass a somewhat broader domain than POPs; PBTs include metals (such as elemental and inorganic mercury), whereas POPs are limited to organic substances (i.e., containing carbon). Domestic activities include the EPA's PBT Chemicals Program to coordinate action regarding these pollutants ([www.epa.gov/pbt](http://www.epa.gov/pbt)), the Toxics Release Inventory (TRI) PBT reporting requirements under the Emergency Planning and Community Right-To-Know Act (EPCRA) ([www.epa.gov/tri/pbtrule.htm](http://www.epa.gov/tri/pbtrule.htm)), and the prioritization accorded PBT parameters when evaluating new chemical notifications under the Toxic Substances Control Act (TSCA) and when registering pesticides under the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA).



Internationally, the Great Lakes Binational Strategy with Canada prioritizes primary and secondary lists of substances slated for "virtual elimination" ([www.epa.gov/glnpo/p2/bns.html](http://www.epa.gov/glnpo/p2/bns.html)). Central to these lists are the 12 priority POPs listed in the Stockholm Convention. With Mexico, under the environmental side agreement of the North American Free Trade Agreement (NAFTA), the United States and Canada have focused their Safe Management of Chemicals (SMOC) efforts on PBTs ([www.cec.org](http://www.cec.org)). Action plans have been developed

for DDT, PCBs, and chlordane, as well as mercury, and are under development for dioxins, furans, and hexachlorobenzene.



Contributing to the difficulties with some POPs are their advantages in the industrial and building sectors. PCBs made excellent dielectric fluids in electrical capacitors and transformers because they are highly resistant to degradation and fire. These same properties contribute to their persistence in the environment and biological organisms. A single application of chlordane, an organochlorine termiticide, provides household termite protection for years. Unfortunately, not all the chlordane stays where it is applied, and it may continue to bioaccumulate far from basement soil and injure or kill creatures for which it was not intended. DDT's ability to repel and injure or kill malaria-carrying mosquitoes can provide several months of household protection, yet ultimately DDT is mobilized and spread outside of the immediate area of application. The benefits of DDT for malaria control, principally due to its persistence, low cost, and past success, remain a major consideration when balancing public health necessities with environmental concerns.

### **The Four POP Parameters: Persistence, Bioaccumulation, Toxicity, Long-Range Environmental Transport**

A suite of four characteristic parameters distinguish POPs from the multitude of other organic chemicals:

#### **Persistence**

Persistence is the propensity of a substance to remain in the environment by resisting physical and chemical degradation, including the effects of biochemical and microbial processes. Persistence is best represented as the degradation of a POP to a non-POP chemical, rather than as declining environmental concentrations that combine degrada-

tion with loss due to dispersion. Persistence is often measured as a half-life, the time (hours, days, months, or even years) necessary for half the chemical to be degraded. Reliance on half-life measures assumes first-order kinetics, where the amount degraded in a fixed period of time is a constant proportion of the amount present initially, i.e.,  $C_t = C_0 e^{-rt}$ , where  $C_0$  and  $C_t$  are concentrations at times zero and  $t$ , and  $r$  is the rate constant for degradation (Figure 1-4). The first-order kinetics assumption may not always apply where early degradation is more rapid, delayed degradation is enhanced through bacterial acclimation and selection, or chiral (mirror image) molecules may be preferentially degraded. The degradation product may also exhibit POPs characteristics. Recognizing the limitations of simplified kinetic assumptions balanced against their pragmatic benefits, half-life values in the different air, soil, water, and sediment media have been included in most POP screening criteria (see Chapter 9, Table 9-1). Persistence screening values for the Stockholm Convention are based on 2 months in water or 6 months in soil or sediment, with a 2-day screening criterion for air transport.

Environmental degradation in the atmosphere occurs principally from reaction of the POP with hydroxyl radicals (OH). The levels of hydroxyl radicals in the air vary considerably with geographic location and time of day and year. Other atmo-

spheric POP degradation processes include photolysis (light-induced degradation) and reaction with ozone and nitrogen oxides. In soil, water, and sediment, microbial degradation is the predominant mechanism. The rate of degradation depends on the types of bacteria present, their concentration, induction relevant to the chemical undergoing degradation, and ambient environmental conditions such as temperature, moisture, and substrate availability. Other processes include photolysis, hydrolysis, and chemical reaction. Details of technical considerations in deriving and using persistence data are contained in the report of a SETAC Pellston workshop, focusing on POPs' persistence and long-range transport issues (SETAC, 2000).

### Bioaccumulation

Bioaccumulation is the phenomenon whereby a chemical reaches a greater concentration in the tissues of an organism than in the surrounding environment (water, sediment, soil, air), principally through respiratory and dietary uptake routes. For example, if the environment in which a fish lives contains 1 µg free chemical/kg of water, and the fish's body contains 5,000 µg chemical/kg body weight, this would equate to a whole-body bioaccumulation factor (BAF) of 5,000 µg (i.e., the Stockholm Convention screening criterion value). The magnitude of bioaccumulation is driven by the hydrophobicity, or water insolubility, of the chemical, principally operating through the ability of a species to eliminate the chemical from its body through excretion and/or metabolism. The terms bioaccumulation, bioconcentration, and biomagnification are variants of this same concept. Bioaccumulation factors measure the preferential accumulation of a chemical in a living organism through all routes of uptake with respect to concentrations in the organism's exposure environment (water, sediment, soil). The term "bioconcentration factor" (BCF) is used when the bioaccumulation factor is based exclusively on uptake from water in laboratory studies, using species (most commonly fish) maintained in a known concentration of pollutant but fed an uncontaminated diet. Biomagnification relates to the most highly accumulative substances (many of the

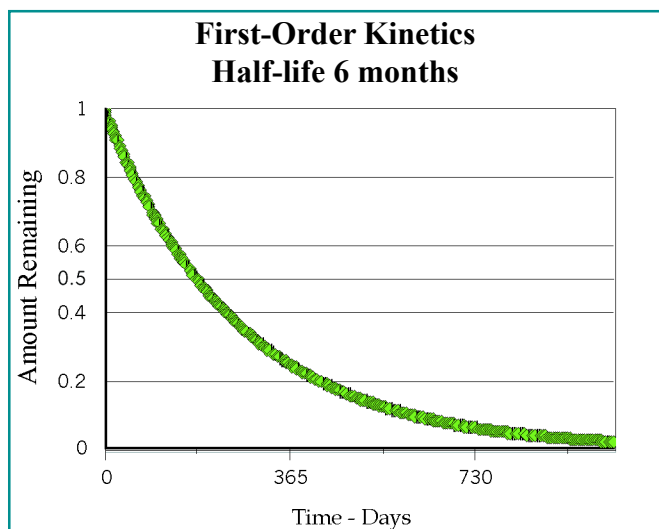


Figure 1-4. First-order decay kinetics diagram.



POPs), where the concentration of the chemical in an organism exceeds that predicted for equilibrium of the organism with its diet, the concentration having been “magnified” in species higher up the food chain (Figure 1-5).

BCF/BAF values can be reported either in relation to the whole-body weight of the test species or in a more standardized manner related to the lipid (or fat) content of the animal, usually a fish. These two measures can be quantitatively linked through the fat content of the animal. This relationship is often simplified by assuming a standard fish fat content to facilitate comparison between chemicals in different study protocols and species, known as lipid normalization (e.g., 3.1% lipid in the case of the Great Lakes Water Quality Assessment for trophic level 3 fish).

A common surrogate for calculating BCF/BAF values is the octanol-water partition coefficient (Kow). This ratio reflects the preferential accumulation of a substance in an oil medium (n-octanol) compared with water. To illustrate, in a cup containing half n-octanol and half water, how much of the chemical placed in the cup would dissolve in the n-octanol divided by the amount dissolving in the water? The Kow is now most often calculated using chemical models. It should be noted that mathematical formulae linking the Kow with BCF/

BAF values do not apply where there is active metabolism of the substance, or for large molecules, and are generally not applicable to organometals. Additional detail on bioaccumulation in aquatic environments is available in the U.S. EPA Great Lakes Water Quality Criteria documents (U.S. EPA, 1995).

### Toxicity

A principal tenet of toxicology is that all substances are toxic at some dose: the dose makes the poison (Paracelsus, 1493–1541). The toxicity of a substance can be reported in a variety of ways, such as acute (short-term) or chronic (long-term) effects, lethal or effective dose levels ( $LD_{50}$  or  $ED_{50}$ , the dose that will kill or affect 50% of test animals), or tissue levels associated with an adverse effect. Whereas certain toxic effects and levels may be easily detected and quantified in laboratory settings, their measurement in the natural environment is considerably more difficult. In field situations, the animal's environment is impossible to control.

This situation is similar to the difficulties experienced with human epidemiological studies. Multiple substances may combine to form a “toxic soup” from which individual chemical contributions can be difficult to disentangle. A corollary of multiple simultaneous exposures is that the cumulative toxicity risk is likely to be greater than when individual chemicals are evaluated in isolation. Furthermore, the low-level effects of interest in field situations may be subtle and difficult to measure, yet vital to species survival. For example, subtle organochlorine-induced neurological impairment may not cause overt effects in a caged, fed, and protected animal, but may be of dire consequence in the complex and dangerous natural environment. Difficulties also occur when attempting to transpose laboratory toxicity data, generally measured as daily dose, to field situations where the metric is tissue concentration of toxin and daily doses are impossible to obtain.

For a further detailed discussion of wildlife toxicology and the effect levels pertinent to POPs' effects on wildlife, see SETAC (1996). Toxicity data on POPs pertinent to humans can be obtained from



Figure 1-5. Simple bioaccumulation diagram.

online databases maintained by the National Library of Medicine ([www.nlm.nih.gov](http://www.nlm.nih.gov); Hazardous Substances Data Bank), the EPA's Integrated Risk Information System (IRIS) database ([www.epa.gov/iris](http://www.epa.gov/iris)), and the Agency for Toxic Substances and Disease Registry (ATSDR) Toxicological Profiles ([www.atsdr.cdc.gov](http://www.atsdr.cdc.gov)).

### Long-Range Environmental Transport

There would be little need for a global treaty if POPs remained close to their site of release. However, on a dynamic planet the forces of air and water, along with the migratory behavior of certain species, move these pollutants to remote locations. A major impetus for the global POPs negotiation was the finding of POPs contamination in the Arctic, thousands of miles from their presumed site of release to the environment. Figure 1-6 shows the intermittent transport of massive dust clouds from Asia and North Africa toward North America. Within a few days these clouds can cross the Atlantic and Pacific Oceans, transporting pollutants and microorganisms along with the dust. Images such as this provide visual confirmation of atmospheric pathways between continents.

Beyond physical transport on dust and sediment particles, empirical data and the physical properties of a number of POPs indicate that these substances may be preferentially accumulating in cold polar climates through global distillation. Certain POPs

that exhibit a particular range of physical properties—often characterized as semivolatile—may evaporate in tropical and temperate climates and condense in cold regions. In a more absolute sense, and independent of whether transport occurs via volatilization or physical transport on particles, once a substance reaches the frozen polar regions, normal physical degradation time scales and half-lives lose their relevance.

It is the combination of persistence, bioaccumulation, toxicity, and long-range environmental transport that makes POPs problematic. All 12 prioritized POPs or their breakdown products rank high to extreme on measurements of these parameters. Low measures on any of the parameters will substantially reduce transboundary concern, although local problems may remain. The parameters also serve as the basis for screening levels in virtually all international POPs agreements, including the Stockholm Convention. In screening for potential POPs using these parameters, the limitations of such an approach are recognized through an emphasis on flexibility and expert judgment in determining the level of risk produced by a substance and what action is warranted.

### POPs History—Cut Short

The story of POPs begins with the growth of the organic chemical industry in the early 20th century, and with foresight will end as we enter the 21st century. DDT was first synthesized in 1874, but its insecticidal properties remained unknown until reported in 1939 by the Swiss chemist Paul Hermann Müller. A skin rash called chloracne was reported by Karl Herxheimer (Herxheimer, 1899) to be afflicting German workers in the chlorinated organic chemical industry in 1899, although the causal agent, dioxin, remained elusive for many decades (Figures 1-7, 1-8). PCBs were first produced commercially in 1929, peaked in 1970, and were banned from production by 1979. Dieldrin and aldrin were first synthesized as pesticides in the United States in the late 1940s. They were named for Drs. Otto Diels and Kurt Alder, who developed the Diels-Alder process for diene (2 double bonds between carbon atoms) synthesis in 1928. With World War II and reconstruction came a broad

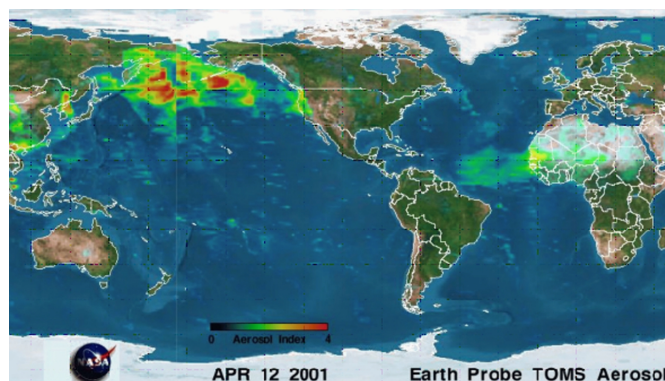


Figure 1-6. False color image of the aerosol abundance in the atmosphere obtained by NASA's Earth Probe TOMS satellite. The aerosol index is a measure of the absorption of solar ultraviolet radiation by airborne particles.

Source: National Aeronautics and Space Administration





Figure 1-7. Agent Orange barrels during the Vietnam War, contaminated with dioxin.

Source: USAF

public awareness of the potential marvels of chemicals such as DDT for disease vector control, exemplified by international efforts seeking to eradicate diseases such as malaria. At the same time, newly developed organochlorine pesticides and herbicides were rapidly filling the needs of the growing agrochemical industry.

But as the use of halogenated, particularly chlorinated, organic chemicals rose in agricultural and industrial sectors, so did warnings about potential adverse consequences to human health and the environment. In 1962, a sentinel event occurred with the publication of Rachel Carson's *Silent*



Figure 1-8. Aerial spraying Agent Orange defoliant, Vietnam.

Source: USAF

*Spring*. Through this book and the surrounding media attention, the public first became aware of a downside to the proliferation of chemicals, with warnings of spring devoid of songbirds. Chemicals intended for insect control were being found to accumulate in the food chain, causing eggshell thinning, chick mortality, and other unforeseen damage. Adding halogen atoms (fluorine, chlorine, bromine, iodine) had been used to make organic molecules more resistant to chemical and physical degradation. The persistence of these organochlorine structures, and the propensity of some to bioaccumulate, were central to the problems being experienced. Increased persistence meant that mistakes made with POPs lingered, such as the prolonged ecological damage caused by chemical spills. Because persistent organochlorine pesticides were nonselective in their toxicity to insects, they caused prolonged killing of both pest insects and beneficial creatures that preyed on these pests. Prolonged, indiscriminate lethality also precipitated secondary pest outbreaks, where insect species not generally considered a problem rose in prominence through disruption of ecological processes.

Beyond these agricultural and ecological concerns lay the human dimension of pesticide and PCB residues in the food supply. Data from tests in rodent species showed that many of these substances were possible or probable human carcinogens. Passage of the Delaney Clause in the 1958 Food Additives Amendment to the Food, Drug, and Cosmetic Act (FDCA) mandated that no carcinogens be added to the food supply—a zero-risk policy. Legal and regulatory decisions to operationalize this requirement stimulated efforts to quantify cancer risk estimates and led to the concept of a *de minimus* concentration, a level below which risks were considered too small to warrant legal attention. The organochlorine POPs, both industrial and chemical, were central to many of these debates. Compounding this pressure for risk quantification was increasing public concern about contaminated industrial sites and toxic chemical pollution. In response, a combination of legislative, regulatory, legal, and voluntary actions ultimately facilitated the development and use of newer pesticides and industrial alternatives in the United States, replacing the problematic organochlorines.



But while uses and levels in the environment, food, and tissue were stabilizing or declining in the lower 48 United States, reports began appearing in the scientific literature of increasing levels in what had been thought pristine, uncontaminated environments. In particular, increasing haze and contamination in the Arctic became a priority concern of northern countries. In 1991, Environment Ministers from the Arctic rim countries (Canada, Denmark/Greenland, Finland, Iceland, Norway, Sweden, Russia, United States; Figure 1-9) established the Arctic Monitoring and Assessment Programme (AMAP; [www.amap.no](http://www.amap.no)) to measure the levels and assess the effects of man-made pollutants in the Arctic environment. Priority attention was directed toward POPs, together with heavy metals and radioactivity. The AMAP efforts, consolidating and supported by domestic programs in Arctic countries (e.g., Canadian Northern Contaminants Program, Jensen et al., 1997), helped focus attention on the long-range transboundary movement of POPs. Long-range environmental transport concerns were reinforced with the finding of elevated POPs levels

in wildlife on remote mid-Pacific islands (Jones et al., 1996).

Transboundary pollution issues, and the opportunity to address them, also gained greater prominence with the easing of Cold War tensions. In 1979, member countries of the United Nations Economic Commission for Europe (UNECE) had signed the Convention on Long-Range Transboundary Air Pollution (LRTAP), initially directed at controlling transboundary sulfur and acid rain pollution. Beyond its name, the UNECE region includes Canada, the United States, western Europe, eastern Europe and newly independent states, and Russia, circling the upper Northern Hemisphere. With a growing understanding of the transboundary nature of POPs pollution, the UNECE-LRTAP agreement offered an ideal vehicle to advance POPs control efforts. In 1992, background work commenced on parallel UNECE-LRTAP protocols to address POPs and heavy metals. Criteria for the priority scoring and selection of POPs were developed, along with a process for reviewing individual chemicals for potential action by the LRTAP parties (AEA, 1995, 1996). Negotiations on a formal POPs protocol began in 1994 and were completed in 1998 ([www.unece.org/enc/lrtap](http://www.unece.org/enc/lrtap)). The United States signed the UNECE-LRTAP POPs protocol, but ratification was deferred pending resolution of the UNEP global POPs negotiations.

### UNEP Global POPs Negotiations

The written record of the global POPs negotiations traces to Agenda 21 of the Rio Declaration on Environment and Development in June 1992 (United Nations, 1993). The foundation and priority for POPs action were enunciated in Objective 17, Protection of the Oceans, and Objective 19, Environmentally Sound Management of Toxic Chemicals. Under protection of the marine environment, Section 17:18 stated:

Many of the polluting substances originating from land-based sources are of particular concern to the marine environment since they exhibit at the same time toxicity, persistence and bioaccumulation in the food chain. There

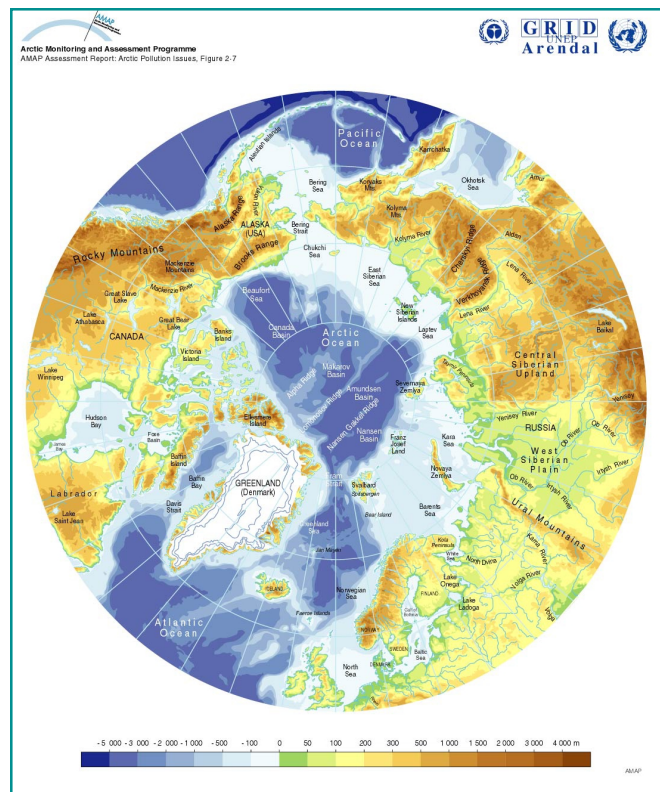


Figure 1-9. Arctic topography and bathymetry.

Source: AMAP.

is currently no global scheme to address marine pollution from land-based sources.

Similar concerns were echoed in Section 19:44, Establishment of Risk Reduction Programmes, where Agenda 21 called for

the phasing out or banning of chemicals that pose unreasonable or otherwise unmanageable risks to human health and the environment and of those that are toxic, persistent and bioaccumulative and whose use cannot be adequately controlled.

In May 1995, these concerns about POPs served as the basis for Decision 18/32 of the United Nations Environment Programme Governing Council (UNEP-GC), which commenced a technical review process to document POPs risks and response strategies. The initial list of POPs consisted of the 12 under discussion at that time by the UNECE-LRTAP Parties. The following principal events trace the chronology and developing consensus for international action on POPs:

*November 1995:* Washington Declaration on Protection of the Marine Environment from Land-Based Activities (<http://www.unep.org/unep/gpa/pol2b12.htm>).

*December 1995:* Inter-Organization Programme for the Sound Management of Chemicals (IOMC) Persistent Organic Pollutants Assessment Report (Ritter et al., 1995).

*March 1996:* Intergovernmental Forum on Chemical Safety (IFCS), second meeting of the Inter-Sessional Group (ISG-2), Canberra, Australia (ISG/96.5a).

*June 1996:* Intergovernmental Forum on Chemical Safety (IFCS) Experts Meeting on POPs: Persistent Organic Pollutants: Considerations for Global Action. Manila, Philippines (IFCS/EXP.POPs./Report.1, 20 June 1996).

*February 1997:* UNEP Governing Council, Decision 19/13C. International action to

protect human health and the environment through measures that will reduce and/or eliminate emissions and discharges of persistent organic pollutants, including the development of an international legally binding instrument (<http://irptc.unep.ch/pops/>).

Decision 19/13C of the UNEP Governing Council in February 1997 constituted the formal agreement to create an intergovernmental negotiating committee (INC) to develop the text for a binding global POPs convention. Negotiations were to commence in 1998 and conclude by 2000. Decision 19/13C provided a detailed mandate to guide the negotiations, centered around the UNEP-GC decision that

immediate international action should be initiated to protect human health and the environment through measures which will reduce and/or eliminate ... the emissions and discharges of the twelve persistent organic pollutants specified in Governing Council decision 18/32 and, where appropriate, eliminate production and subsequently the remaining use of those persistent organic pollutants that are intentionally produced.

Negotiations began in Montreal, Canada, in June 1998, following a series of awareness-building workshops in developing countries to inform governments on scientific issues concerning POPs. Subsequent negotiating sessions were held in Nairobi (January 1999), Geneva (September 1999), and Bonn (March 2000), culminating in the agreement reached in Johannesburg (December 2000) (Figure 1-10). Technical considerations on criteria for the addition of substances were covered during two criteria expert group (CEG) meetings in Bangkok (October 1998) and Vienna (June 1999). Signing of the treaty by the United States and 90 other nations was held in Stockholm, Sweden, in May 2001, hence the designation Stockholm Convention (Table 1-1).

The treaty is currently open for signature and ratification by countries. Ratification by individual countries confirms their signature of the treaty, following review and consent through the domestic





Figure 1-10. Concluding the POPs negotiations, Johannesburg, South Africa, December 2000.

Source: International Institute for Sustainable Development.

political, legal, and legislative process. The Convention will enter into force after it has been ratified by 50 nations. Entry into force applies only to parties that have ratified the Convention.

## Science Clarifications—Separating Reality from Assumptions

Before detailing POPs case studies in the United States and links to long-range environmental transport, it is worthwhile clarifying some assumptions and misconceptions that often occur when evaluating POPs. In particular, an understanding of POP problems requires a movement beyond standard considerations of timing, causes, and effects of pollution. The evaluation must also consider the peculiar impacts of extremes of persistence, bioaccumulation, toxicity, and long-range environmental transport.

- \* *POPs pesticides are still being produced:* From the United States' perspective, the listed POPs pesticides (all organochlorines) are generally considered "dinosaur" chemicals from a bygone era whose production has ceased. They have been superseded by more carefully tailored, selective, and less persistent and

**Table 1-1. Elements of the Stockholm Convention**

Objective: (Article 1)	"... to protect human health and the environment from persistent organic pollutants."
Article 2	Definitions
Article 3	Measures to reduce or eliminate releases from intentional production and use
Article 4	Register of specific exemptions
Article 5	Measures to reduce or eliminate releases from unintentional production
Article 6	Measures to reduce or eliminate releases from stockpiles and wastes
Article 7	Implementation plans
Article 8	Listing of chemicals in Annexes A, B, and C
Article 9	Information exchange
Article 10	Public information, awareness, and education
Article 11	Research, development, and monitoring
Article 12	Technical assistance
Article 13	Financial resources and mechanisms
Articles 14–30	Interim financial arrangements; reporting; effectiveness evaluation; noncompliance; settlement of disputes; conference of the parties; secretariat; amendments to the Convention; adoption and amendment of annexes; right to vote; signature; ratification, acceptance, approval or accession; entry into force; reservations; withdrawal; depositary; authentic texts

bioaccumulative alternatives. These alternatives, although in some cases potentially more acutely toxic to applicators (e.g., some organophosphates), are usually less prone to inducing pest resistance, lead to fewer secondary pest infestations, and result in less food contamination. But, as the UNEP POPs negotiations demonstrated, on a world scale POPs are not gone, with many still being produced and used, especially in developing countries. A number of factors, principally economic, contribute to this continuing use. Organochlorine pesticides are often cheap, easy to produce, and off-patent. Their persistence contributes to their perceived economic benefit, because one application of chlordane termiticide or DDT insecticide can last much longer than modern alternatives. Finally, some organochlorine pesticides are perceived to exhibit lower acute mammalian toxicity, and are applied in developing countries with less emphasis on training and expensive protective equipment for applicators.

- \* *All POPs are not the same:* Although the 12 priority substances exhibit similar high to extreme measures for persistence, bioaccumulation, toxicity, and long-range transport, there is large variability in other physical properties. Values for volatility, solubility, and Henry's Law constant (water-air partition coefficient, important for air transport modeling) vary by up to 5 orders of magnitude between substances (100,000-fold). A consequence is that not all POPs are expected to exhibit the same propensity for global distillation (Wania and Mackay, 1996).
- \* *POPs concentrations are higher near their site of release:* The focus on a global POP convention and transboundary pollution should not obscure the reality that the highest POP concentrations are generally found close to the site of release. Problems in the United States are generally homegrown. This proximity does not negate the importance of international action, but emphasizes the need for care in determining appropriate actions. For example, POP levels in marine mammals in the lower 48 United

States are often much higher than those found in Alaska. However, marine mammals constitute a dietary staple for some subsistence Alaska natives. Their health and cultural well-being are threatened by substances from beyond U.S. borders that they neither used nor derived benefit from and yet now contaminate their environment.

- \* *Low concentrations in remote locations do not preclude a substance being a POP:* Concentrations in remote locations reflect a combination of POP parameters, emission levels, and accumulation time. For a substance such as endrin, the isomer of dieldrin, the relatively low concentrations found at long range are principally a result of the lower historic use levels in temperate climates. Endrin has POP parameters similar to dieldrin, so any increased use of endrin as a substitute for dieldrin would be expected to lead to similar long-range risks.
- \* *Contemporaneous appraisals of pollution cause and effect are insufficient:* Often when we think of environmental pollution we equate contemporary emissions with contemporary concentrations and effects on those exposed. These assumptions do not hold for POPs and must be modified by a more detailed examination of the science underlying POP properties.
  - *Cumulative dose measures are preferable.* The long environmental and biological half-lives of POPs result in a cumulative dose, where current tissue concentrations are a modified sum of past exposures. For persistent chemicals, tissue-concentration metrics that integrate dose, rather than daily dose measures, should be used to assess toxic risk (unless daily dose is interpreted consistent with half-life considerations).
  - *Concentrations will build up for decades.* As a result of cumulative exposure, it is incorrect to assume that, if a pesticide has been used for several years at a consistent level, the concentrations now in the environment represent the worst-case scenario.



Persistence values for many of the POPs may be of such duration that, at a steady use rate, environmental concentrations could continue increasing for more than a century. Thus, actions to assess impacts and reduce use must be guided by predicted concentrations at the end of the accumulation cycle.

- *Momentum.* Solving POP pollution problems takes time. These substances persist and recycle in the environment, potentially moving long distances. For those environments and peoples at the receiving end of this migration—e.g., sinks such as the Arctic—cessation of release at the source may not end POP accumulation, which will take considerably longer.
- *The world of the future will be different.* We must look beyond the world of the present and to the future when evaluating potential long-term benefits of the Stockholm Convention. As illustrated in Chapter 8, the world of the future will have

higher population levels (Figure 1-11), increased industrial activity, and chemical development and production concentrated in what are now developing countries. A central consideration should be the future POP emissions potential and impact on the United States from these countries, if unconstrained by an implemented Stockholm Convention.

- \* *A toxic legacy of POPs at birth.* Growing embryos and newborns of all species undergo extremely complex developmental changes to reach their peak performance potential (Figure 1-12), necessary to survive in a competitive and often dangerous world. This period of development is protected by biological defenses developed over eons of evolution, from maternal detoxification and placental barriers to the rich nutrients and proteins in mother's milk. POPs thwart these barriers through their resistance to metabolism, passage across biological membranes facilitated by their relatively low molecular weight, and high lipid solubility lead-

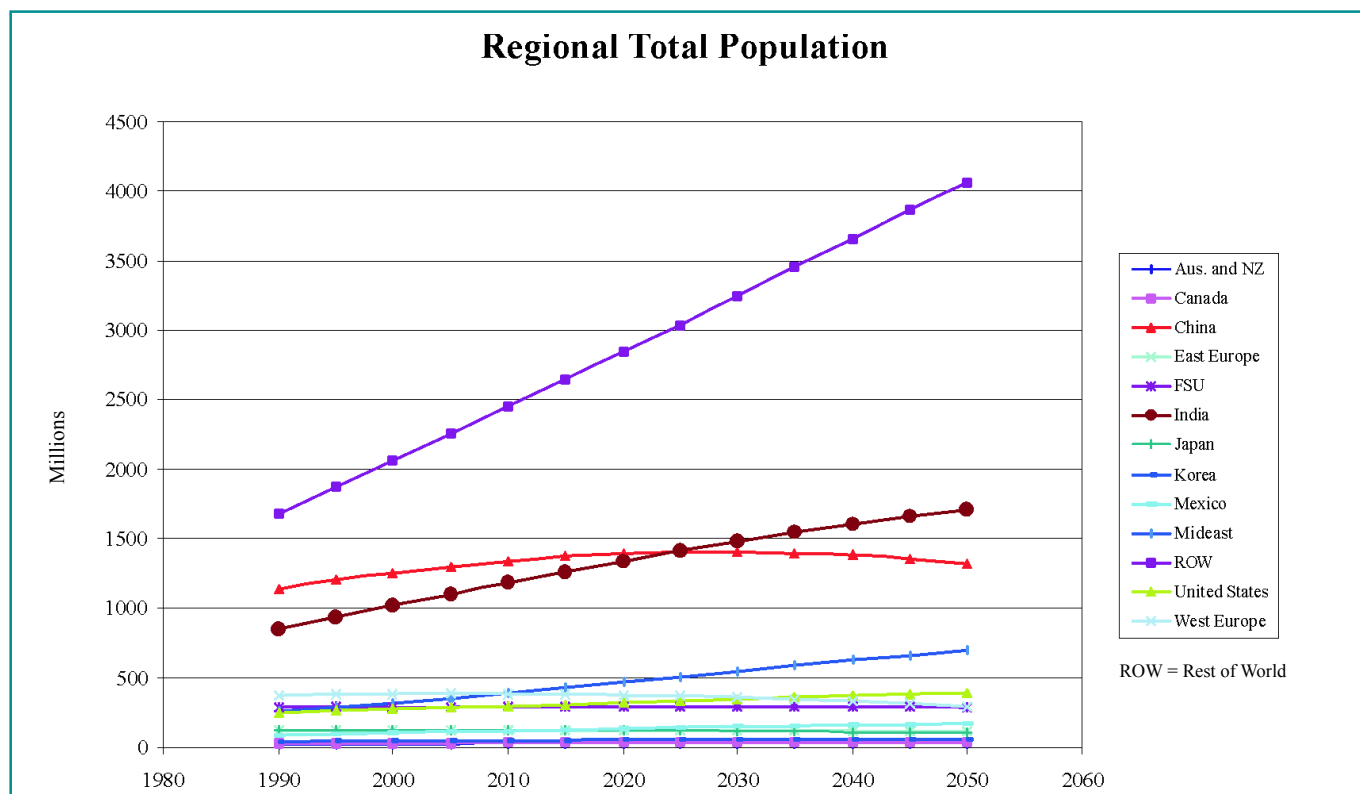


Figure 1-11. World population growth projections.



Figure 1-12. Normal four-month human fetus, in utero ultrasound image.

Photo: B. Rodan

ing to concentration in body fats. The high energy demands of growth and development are also best satisfied through high-fat-content milk, the ideal POP dosing mechanism. Indeed, through lactation and nursing her young, a female mammal can purge herself of POPs by transferring the lipophilic (i.e., concentrate in fat) substances to her offspring. Toxic effects during sensitive periods of development have not been adequately studied. All too often, scientists and regulatory agencies must account for risks to the newborn by relying on data derived from adult animals or limited reproductive and physical development studies in rodents.

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